Appendix F

ESTIMATING THE EXTENT OF THE OLIGOHALINE ZONE IN THE NORTH FORK OF THE ST. LUCIE ESTUARY UNDER LOW FLOW CONDITIONS

Chenxia Qiu, SFWMD

SUMMARY

The location of the 5 ppt isohaline in the North Fork under steady-state conditions is estimated using two methods: a 1-d analytical solution and a 2-d hydrodynamic model (RMA). The 5 ppt isohaline is traditionally considered to be the transition between the saltier mesohaline and the fresher oligohaline habitats. Its location is used here to define the downstream extent of viable oligohaline habitat under low flow situations. The 1-d analytic method is calibrated using salinity data at Kellstadt Bridge (Florida Oceanographic Society station 1) and flow data at the Gordy Road Structure in 1999-2000. Hu (2000) calibrated the 2-d RMA model at Roosevelt Bridge in St. Lucie Estuary. A logarithmic relationship is developed relating the salt intrusion position to discharge rate. The relationship is similar for both solution methods. This relationship can be used to estimate the extent of the viable oligohaline zone in the riverine portions of the North Fork.

BACKGROUND

This work is conducted as part of the Indian River Lagoon Restoration Feasibility Study and also as part of the effort to establish Minimum Flow and Levels (MFLs) for the St. Lucie Estuary. Protection of a viable oligohaline habitat depends in part on the maintenance of sufficient flows within the riverine reaches of the St. Lucie watershed. Since most of the riverine portions of the watershed are in the historic North Fork, this paper is limited to NF modeling. Previous hydrodynamic modeling (Hu, 2000) within the St. Lucie estuary focused on periods of moderate to high runoff when the riverine portions of the estuary were fresh. For this reason, previous modeling did not extend into the riverine portions of the estuary.

Minimum flow conditions are associated with droughts and periods of low rainfall. Under low flow conditions, salinity throughout the estuary increases and the oligohaline area is reduced as higher salinity destroys or displaces oligohaline flora and fauna. This MFL work is directed at estimating the extent of the oligohaline under various low flow conditions. Since flows are relatively stable during low flow periods it is assumed that steady-state solutions can adequately predict salinity within the upstream reaches.

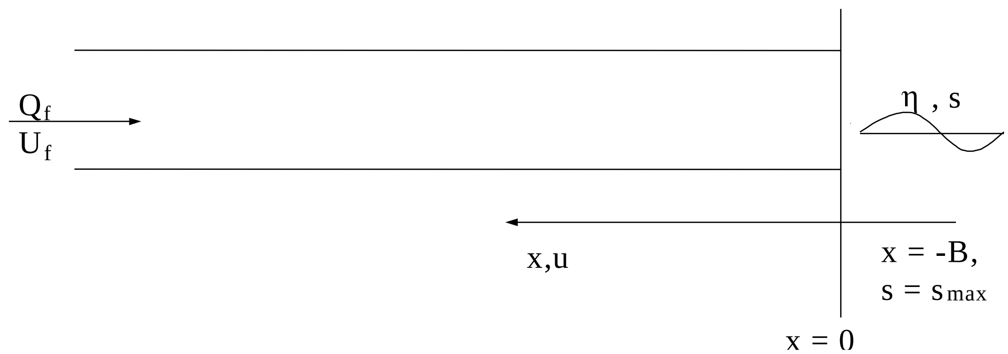
This memo describes two steady-state methods for predicting the location of the 5 ppt isohaline. The calibration of the analytical method is also described. The methods are applied to two minimum flow situations (described elsewhere as the end of a 1-in-10 year climatic drought, Konyha). One MFL situation is North Fork flows under pre-developed (NSM) conditions. The other situation is flow from today's watershed (1995 Base) under the same low rainfall conditions. The paper finds that equivalent flow-location relationships exist for both 1995 base and NSM conditions using either the analytical or RMS method. The resulting simple flow-location relationship is applied elsewhere in the continued development of MFL criteria.

METHOD 1, 1-D ANALYTICAL SOLUTION

Basic Equations

The objective is to calculate the location of isohaline, such as 5 ppt or 10 ppt salinity in a tidal driven channel with freshwater discharge. The method described below (**Figure F-1**) come from Ippen (1966).

At x=0, ocean end; at t=0, it is low tide



Q_f and U_f are fresh water discharge and velocity, s_{max} is the maximum salinity at the tidal boundary, B is the distance from tidal boundary to ocean where salinity reach s_{max} at low tide

Figure F-1. Sketch of salinity intrusion in tidal influenced channel at low tide

$$\frac{\partial s}{\partial t} + u\frac{\partial s}{\partial x} = \frac{\partial}{\partial x}\left(D_x \frac{\partial s}{\partial x}\right) \qquad (1)$$

At any point, the flow velocity in the channel is equal to the sum of the velocity due to tidal motion u(x,t) and the fresh-water velocity $-U_f$, thus

$$\frac{\partial s}{\partial t} + u(x,t)\frac{\partial s}{\partial x} - U_f\frac{\partial s}{\partial x} = \frac{\partial}{\partial x}\left(D_x \frac{\partial s}{\partial x}\right) \qquad (2)$$

Where $D_x(x,t)$ is the diffusion coefficient.

Solution

Salinity Distribution at Low Tide

$$\ln \bar{s} + C_2 = -U_f \int \frac{dx}{D_x} \qquad (3)$$

Diffusion without Density Difference

The diffusion coefficient can be stated as:

$$D_x = 14.2hu \frac{\sqrt{2g}}{C_c} = 7.1hu\sqrt{f}\ , \quad C_c = \sqrt{8g/f} \qquad (4)$$

The average value of D_x in a tidal cycle linearly depends on u, which is computed from tidal propagation and decreases with x in upstream direction. For uniform cross sections, a simplest functional relationship can be used:

$$D_x = \frac{D_0 B}{x+B} \qquad (5)$$

$$\text{Therefore, } \ln \frac{c}{c_0} = -\frac{U_f}{2BD_0}(x+B)^2 \qquad (6)$$

at x=-B, c= c_0.

Diffusion with Density Difference

$$\ln \frac{s}{s_{\max}} = -\frac{U_f}{2BD_0^{'}}(x_l + B)^2 \qquad \text{for } (x_1 + B) > 0 \qquad (7)$$

The minimum salinity intrusion length at low tide:

$$L_m = x_l = B\left(\sqrt{-\frac{2D_0^{'}}{U_f B}\ln\frac{s}{s_{\max}}} - 1\right) \ (8)$$

The maximum salinity intrusion length at high tide is in the range of L_m and L_m+B.

Determine B and D_0'

$$B = \frac{u_{\max}}{s}(1 - \cos s t_B) \qquad (9)$$

Because the salinity is in the range of 5-15ppt, assume $D_0' = D_0$

$$D_0^{'} \sim h u_{\max} \frac{\sqrt{2g}}{C_c}, \quad C_c = \frac{1}{n} R^{1/6}, \quad R = \frac{bh}{b + 2h} \qquad (10)$$

Where t_B is the time the salinity at the entrance reaches the maximum value s_{max}, s_{max} is the maximum salinity at low tide at $x_l = 0$. The final D_0' is obtained from calibration. t_B and s_{max} can be identified from salinity profile at the ocean end.

Input Parameters

Table F-1 Input Parameters

Symbol	Parameters	Sources
b	Width	Cross section profile
h	Depth	Cross section profile
n	Manning coefficient	
u_{max}	Maximum velocity at the tidal end boundary	Tidal boundary
σ	Tidal frequency	Tidal boundary
U_f	Freshwater velocity	Fresh water discharge Q_f and river cross section area A
s_{max}	Maximum salinity at tidal end boundary	Salinity series at tidal boundary
t_B	time the salinity at the entrance reaches the maximum value s_{max}	Salinity series at tidal boundary

Implementation Procedures

Determine σ, u_{max}, and s_{max} from tidal boundary condition.

Determine river depth h, and calculate U_f=Q/A, where Q is the freshwater discharge rate m^3/s, A is the cross section area of river.

Determine t_B and s_{max} with salinity series boundary condition.

Calculate B and D_0'from Equation (9) and (10).

Calculate minimum salinity intrusion at low tide with equation (8).

Calibration

The calibration dataset is composed of three parts, Florida Oceanography Society (FOS) station 1 salinity data, Gordy Road Structure flow data, and Kellstadt Bridge salinity and current data maintained by USGS. FOS salinity data on North Fork was taken by volunteer every week since 1998. It is located at 1 mile north of Prima Vista Bridge (section N044), or 4-5 mile north of Kellstadt Bridge (N067) (Longitude 80°19.887'W, Latitude 27°19.724'N).

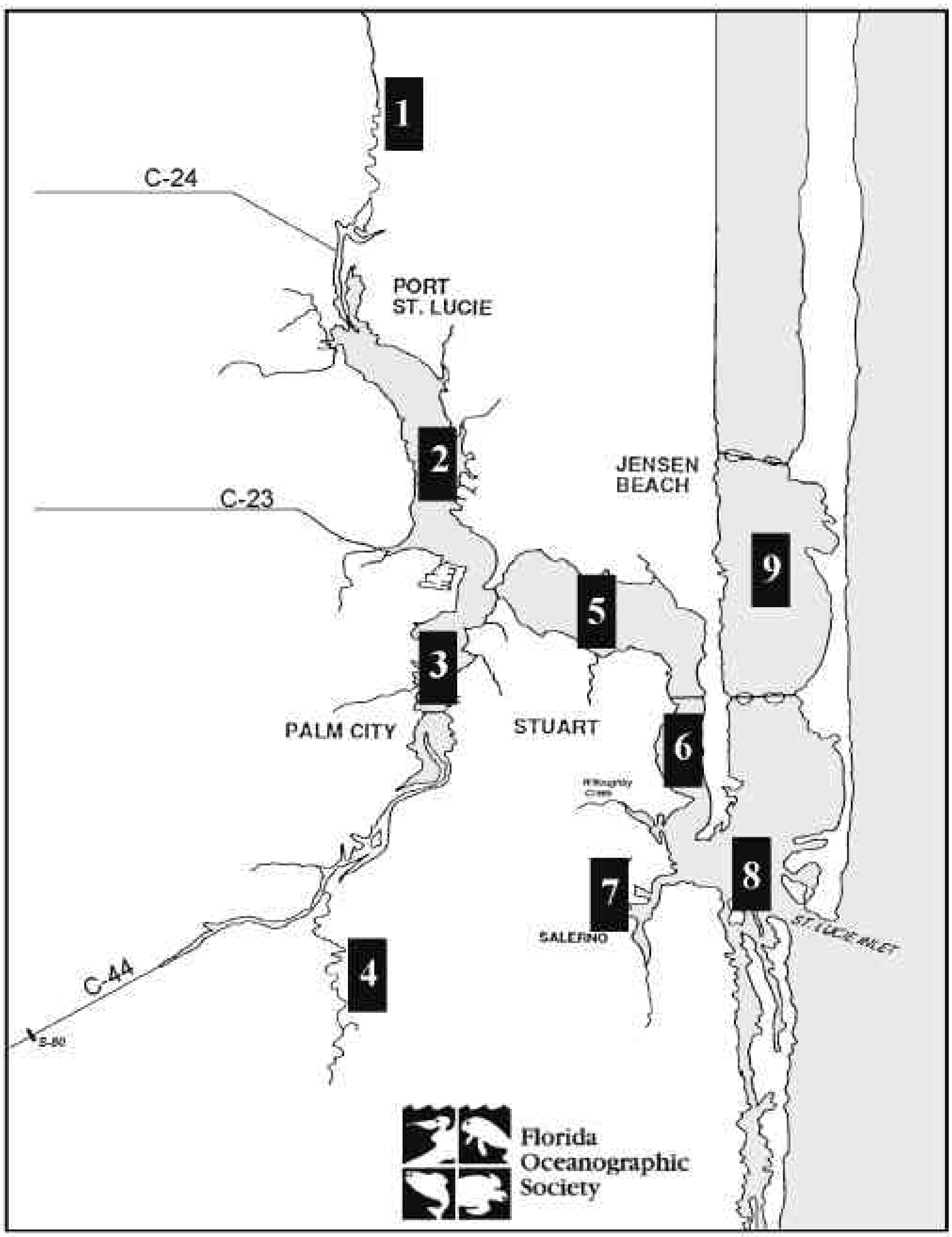


Figure F-2. FOS Monitoring Stations

Kellstadt Bridge station was monitored by USGS ended in 2000. The monitoring data include water surface elevation, current, and salinity at top and bottom layers.

The discharge rate at Gordy Road Structure on 10 Mile Creek was monitored since 1999. The discharge rate on North Fork is estimated based on drainage area (**Table F-2**). The approximation in North Fork discharge estimation is probably one of the greatest error term in this simulation.

Table F-2 North Fork discharge derived from Gordy Road Structure discharge

Drainage basins	Drainage area (acres)
10 Mile Creek	29,380
5 Mile Creek	7,000
North Fork-total	105,613
North Fork-uncontrolled area flowing into North Fork	63333
$Q_{NF} = Q_{TMC} * (1 + 63,333/29,380) = Q_{TMC} * 3.16$ Q_{NF} is the total discharge on North Fork and Q_{TMC} is the discharge on Ten Mile Creek measured at Gordy Road Structure	

Based on 22 cross-section profiles on North Fork, the river is deeper and wider (230 ft) down from Prima Vista Bridge with meandering (N035-N072). To the upper reach from Prima Vista Bridge (N01-N035), the river is narrower (85 ft) and shallower. During calibration step, the width is fixed constant to 6.5 ft between FOS station 1 and Kellstadt Bridge. Three calibration scenarios were selected based on the comparison of overlap periods among these 3 datasets (**Table F-3**).

Table F-3 Calibration scenarios

Calibration scenarios	March 19, 2000	January 23, 2000	December 19, 1999
Fresh water discharge Q_f (cfs)	90	180	260.9
Kellstadt Bridge salinity (ppt)	12	8	3
Salinity at FOS station 1 (north of Prima Vista Bridge) (ppt)	4	2	1.2
Maximum Tidal velocity u_{max} (m/s)	0.3	0.3	0.2
Maximum salinity at tidal end (ppt)	14.8	10.2	5
Minimum salinity at tidal end (ppt)	11	5	1.5
Width (d) ft	230		
Depth (h) ft	6.5		
Length (mile)	6.4		
Manning coefficient	0.04		
t_B	0.45 T (T is tidal period)		

The diffusion coefficient is crucial for salinity intrusion due to tidal mixing and density gradient. The density gradient effect is reflected in freshwater discharge and salinity at tidal end. To account for this, diffusion coefficient is adjusted with a correction factor in prediction.

$$D_0^{'} = D_0 \cdot f(Q_f) \cdot f(\frac{s_{\max}}{s_{\min}}) = D_0 \cdot \frac{Q_f\,(calibration\ base)}{Q_f} \cdot \frac{\ln(\frac{s_{\max}}{s_{\min}})(calibration\ base)}{\ln(\frac{s_{\max}}{s_{\min}})} \qquad (11)$$

Analytical solution is limited with uniform sections. Therefore, average depth is adjusted to 5 ft at low flow condition based on the 2-d simulation result, which will be described in Method 2.

With the progress of tide into river, the velocity amplitude is damped exponentially. In addition, the celerity of wave is reduced by a factor related to wave length. This factor is 0.71 to 0.94 (Ippen, 1966). A conservative correction factor of 0.9 is used.

The 1-d analytical solution is limited with simplifications. Through the calibration and prediction process, river depth, river width, maximum salinity and velocity at tidal boundary are identified as sensitivity parameters. River depth and width are simplified as uniform. The measured velocity at Kellstadt Bridge by USGS is used in prediction. In addition, diffusion coefficient is assumed linearly decreased with the propagation of tide. All these approximations introduce uncertainty in prediction and reflect the limitation.

METHOD 2 - 2-D SIMULATION ON EXTEND ESTUARY GRIDS WITH RMA MODEL

The RMA finite element grid was extended from Kellstadt Bridge to Gordy Road Structure. The new grid is shown in **Figure F-3**. 2-d RMA model is calibrated around Roosevelt Bridge in St. Lucie Estuary by Hu (2000). Due to the time limit, it is not further calibrated on North Fork.

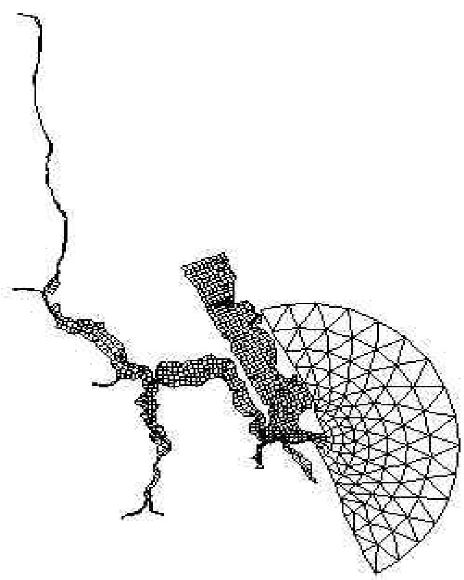


Figure F-3. 2-D Simulation Grid for North Fork and St. Lucie Estuary

RESULTS

5 and 4 prediction scenarios are selected for 95 base and NSM respectively based on the time periods when discharge is relatively stable (**Table F-4**, **Figure F-4** and **Table F-5**, **Figure F-5**).

Table F-4 Prediction Scenarios for 95 Base

Julian Day	27-42	95-105	19-24	74-79	112-117
Q_f (cfs)	235	130	80	35	25
s_{max}		9.5	13	15	18
s_{min}		6	9	10.5	13
s_{avg}	3.8	8.5	11	12.5	15
L_{avg} (mile)	0	3.4	5.5	7.5	12.6
% of NF length	0	0.14	0.22	0.3	0.5
L_{avg} compared to RMA4 result	0	5.3	4.0	6.0	8.2
% of NF length	0	0.21	0.16	0.24	0.33

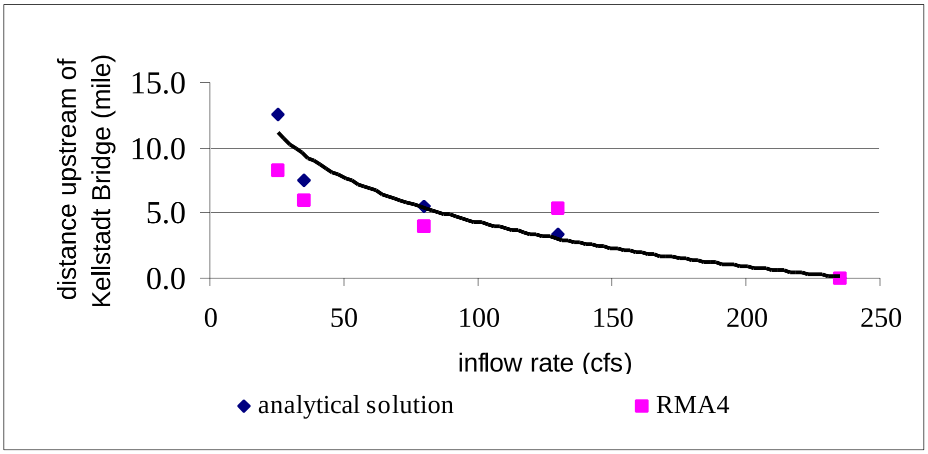


Figure F-4. Location of 5 ppt Isohaline: 1995 Base

Table F-5 Prediction scenarios for NSM

Julian Day	112-119	10-30	52-60	34-50
Q_f (cfs)	20	80	100	120
s_{max}	17.5	14	14	10
s_{min}	14	9	8	6.5
s_{avg}	16	11	10	8
L_{avg} (mile)	13.4	5.5	4.2	3.2
% of NF length	0.54	0.22	0.17	0.13
L_{avg} compared to RMA4 result	10.9	5.7	3.4	2.1
% of NF length	0.43	0.23	0.14	0.08

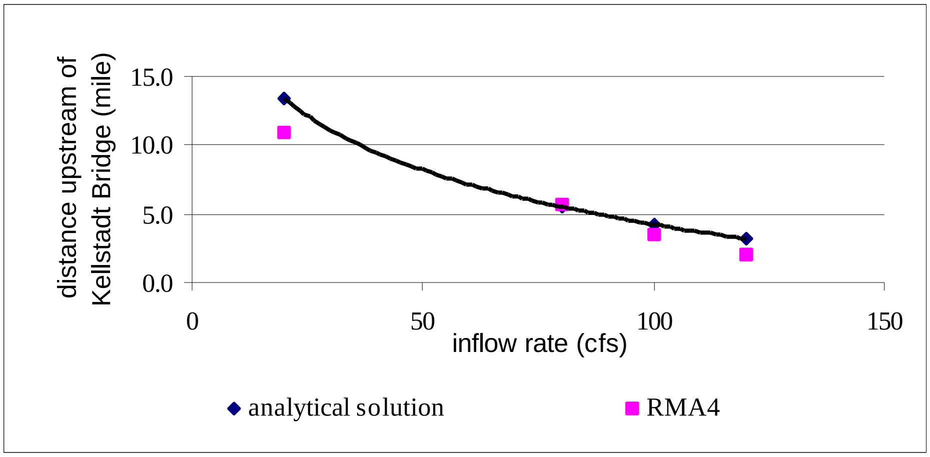


Figure F-5. Location of 5 ppt Isohaline: NSM

Based on the results from two methods, the location of 5 ppt isohaline and discharge rate has these relationships:

$L=-4.9\ \ln(Q_f)+27$ 95 base

$L=-5.7\ \ln(Q_f)+30.5$ NSM

When discharge is larger than 230 cfs for 95 base, the 5 ppt isohaline is down Kellstadt Bridge on North Fork.

CONCLUSION

Prediction of the location of isohaline on North Fork is conducted with simplifications for a quick solution. Compared with Kellstadt Bridge salinity data from USGS, it is concluded that RMA result underestimated the salt intrusion length on North Fork, while 1-d analytical solution result is limited by too many simplifications. Due to the limitation of time, the accuracy of the result is compromised.

This simulation will be applied in the determination of oligohaline zone on North Fork under minimum flow condition for three scenarios, 95 base, Natural System (NSM) and year 2050.

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